MACROINVERTEBRATES AND RESERVOIR DISCHARGE:

EFFECTS OF CAVE RUN LAKE ON TAILWATER COMMUNITIES

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Accepted by the faculty of the School of Sciences and Mathematics, Morehead State University, in partial fulfillment of the requirements for the Master of Science degree.

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ABSTRACT

MACROINVERTEBRATES AND RESERVOIR DISCHARGE: EFFECTS OF CAVE RUN LAKE ON TAILWATER COMMUNITIES

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Morehead State University, 1980

Director of Thesis:

To evaluate the effects of reservoir discharge, a series of quantitative and qualitative macroinvertebrate samples were taken upstream and downstream from Cave Run Lake. Data were compared with pre-impoundment faunal surveys and pre- and post-impoundment water quality and streamflow data.

Results showed reduced diversity, complete elimination of some taxa, and dominance by attached, filter-feeding insect larvae downstream from the dam. There was a trend toward increased diversity and recovery of normal community composition with increasing distance downstream. Downstream temperatures, streamflow, and water quality were altered by impoundment.

Increased epilimnetic release capacity resulting from proposed modification of the reservoir outlet structure should effect recolonization of the tailwater by organisms intolerant of present conditions. The mayfly Stenonema is suggested as an indicator organism.

Accepted by: M E Bryan, Chairman

Jerry F Howell, Jr

Gerald DeMoss

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

The Licking River

The Licking River basin (Figure 1) covers an area of 8,420 square kilometers (km^2) in eastern Kentucky, its upper reaches draining Cumberland Plateau sandstones, shales and coals of Pennsylvanian age. The larger downstream portion of the basin drains Mississippian and older limestones, sandstones and shales of the Inner Bluegrass, Outer Bluegrass and Knobs regions.

Major Licking River tributaries in the Cave Run Lake vicinity are Elk Fork, which drains a heavily stripmined area just upstream from the reservoir; Beaver Creek and North Fork, both relatively undisturbed streams; and Triplett Creek, which flows into the river about nine km downstream from Cave Run Dam.

Water in the upper portion of the basin generally has low concentration of hardness, alkalinity, dissolved solids and nutrients, but contains relatively high concentrations of iron, manganese and suspended solids. In the river proper, pH ranges from 6.5 to 7.5, but some small tributaries are quite acidic because of coalmine drainage (U. S. Geological Survey and U. S. Army Corps of Engineers computer file data). The water quality

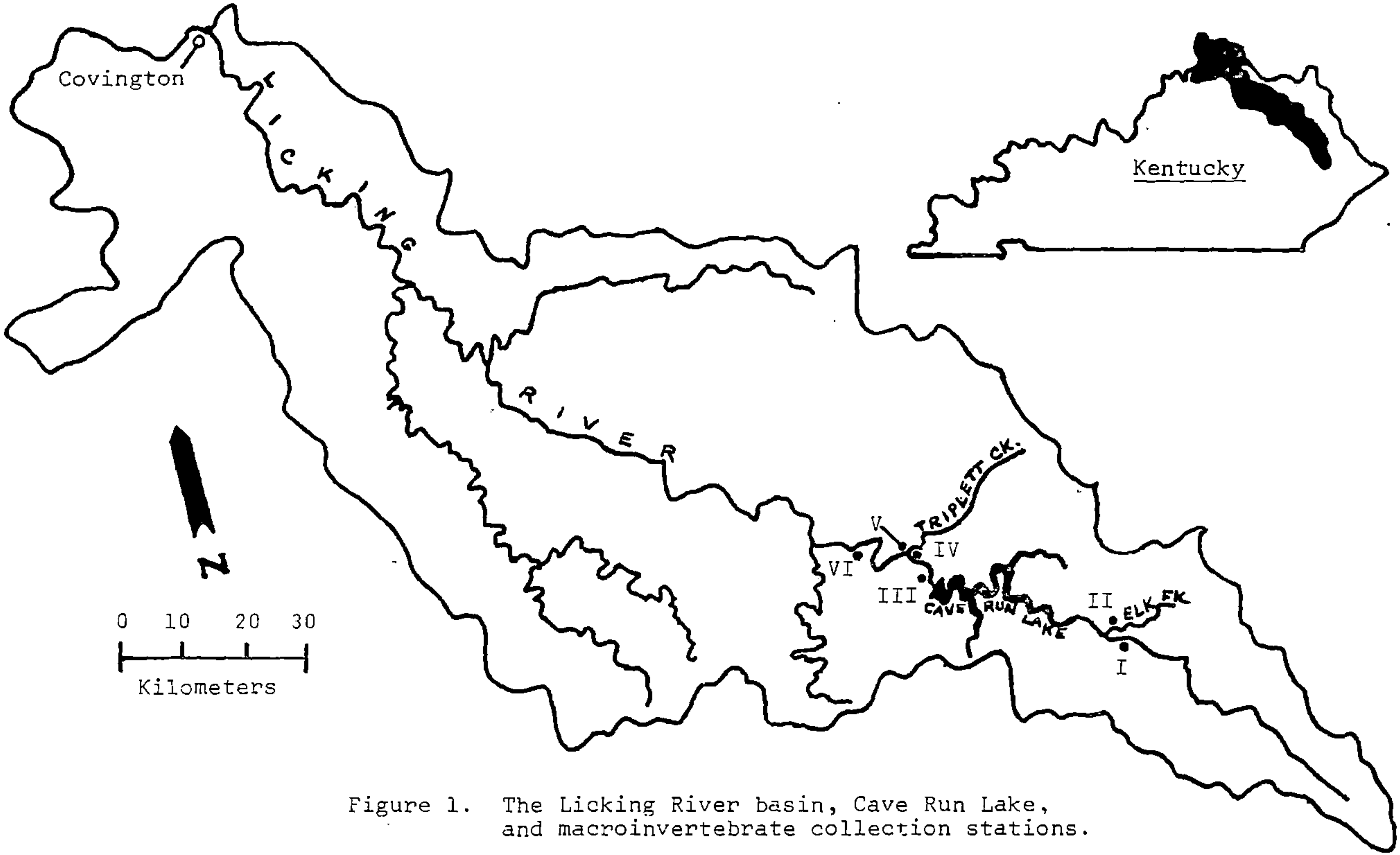

Figure 1. The Licking River basin, Cave Run Lake, and macroinvertebrate collection stations.

management plan for the basin (Kentucky Department for Natural Resources and Environmental Protection, 1976) contains detailed water quality, physiographic and demographic information.

Cave Run Lake

In January 1974, approximately 80km of the Licking River and its tributaries were impounded when the United States Army Corps of Engineers (USCE) closed the gates of Cave Run Dam to form Cave Run Lake, a multipurpose reservoir. Although primarily designed for flood control, other project objectives were downstream water quality control (by low-flow augmentation), recreation, and fish and wildlife enhancement.

At summer pool elevation of 222.6 meters (m) above mean sea level (msl), the lake has a surface area of 3,288 hectares and a storage volume of $2.74 \times 10^8 m^3$. In autumn, the reservoir level is lowered to 220.7m above msl to provide additional flood control storage.

The Cave Run Dam and outlet structure are located 280km above the confluence of the Licking River with the Ohio River at Covington, Kentucky. Discharge from the reservoir passes through a concrete conduit in the base of the earth and rock-fill dam and is controlled by a system of gates in the outlet structure. Water volumes of up to 10.6m^3 per second, slightly more than one-third of average discharge, can be released through a low-flow bypass system fed by six multi-level selective withdrawal gates which draw water from the upper levels of the reservoir. This system allows water temperatures to be controlled for downstream fishery maintenance during periods of reservoir stratification. Large-volume releases are controlled by a pair of service gates at the lowest level of the outlet structure.

Because of the small capacity of the low-flow bypass system, releases from the service gates are required occasionally when the reservoir is thermally stratified. Hypolimnetic water released during these periods typically has concentrations of dissolved oxygen less than 0.5 milligrams per liter (mg/ℓ), high concentrations of dissolved manganese and iron, and low oxidation-reduction potential. Hydrogen sulfide is also present in these releases, although too few measurements have been made to determine actual concentrations. During hypolimnetic releases in midsummer, downstream water temperatures are several degrees Celsius (°C) colder than is normal for the season (see Chapter IV).

Although the turbulence of releases provides satisfactory aeration (increasing dissolved oxygen concentrations from a few tenths of a mg/ℓ to near-saturation), the problems of low temperature, dissolved metals and hydrogen sulfide persist for considerable distances downstream.

USCE has attempted to ameliorate the problems associated with hypolimnetic releases by careful reservoir regulation. By permitting the pool to fluctuate within limits compatible with reservoir uses, epilimnetic releases throughout late summer and autumn, and delaying autumn drawdown until reservoir destratification, the discharge of large quantities of poor quality water has been kept to a minimum. To reduce severity of temperature and chemical shock to aquatic organisms, flows are increased gradually, at a maximum rate of approximately $29m^3$ per second per hour, and hypolimnetic water is mixed with epilimnetic water by operating the bypass system at capacity during these releases (USCE, 1975). The Corps also has been studying modification of the outlet structure to increase epilimnetic discharge capacity as a permanent solution to hypolimnetic release problems. Several methods of artificial mixing and destratification have been proposed as alternatives to structural modification.

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Objectives of this Study

Routine observations indicated that the considerable changes in downstream water quality and flow characteristics caused by the construction and operation of Cave Run Dam had affected the macroinvertebrate fauna. By measuring community composition at varying distances downstream from the reservoir, and comparing it with upstream stations, pre-impoundment studies, and water quality and streamflow data analyses, an attempt was made to measure the magnitude of change and the importance of various stress factors. By analyzing samples taken over a period of years and at different seasons, it was attempted to determine if there had been a trend toward recovery through ecological stabilization in the six years since reservoir impoundment.

It was anticipated that this study would provide baseline data and identify indicator organisms useful in future investigations, especially those associated with effects on macroinvertebrate fauna of the planned outlet structure modification.

CHAPTER II

REVIEW OF THE LITERATURE

Benthic Studies of Rivers and Streams

Hynes (1970) and Hawkes (1975) cited the general lack of biological data for large streams and the difficulty involved in studies of this type. River macroinvertebrate communities and their responses to various environmental conditions were described in benthic investigations of large streams and rivers by Bloesch (1977), Dusoge and Wisniewski (1976), Gore (1977), Minshall and Minshall (1978) and Rosenberg and Wiens (1978). Ball and Bahr (1975) summarized an intensive ecological study, including benthos, of the Red Cedar River in Michigan. Macroinvertebrate data from several studies related to point sources of pollution were summarized by Hawkes (1962). Zanella (1974) presented a general description of river surveys combining biological indicators and water quality data.

In benthic investigations of small Kentucky streams, Barrett (1977) found that sediment from stripmining reduced macroinvertebrate diversity and Minshall (1954 and 1967) studied the relationships of macroinvertebrate communities to a number of environmental factors, including food sources, temperature, substrate, and flooding.

Few data have been published on Licking River invertebrate fauna. A unpublished Cave Run Lake pre-impoundment study by Clinger (1974) is the most complete and systematic work to date in this drainage basin. Resh (1975), in a paper on caddisfly distribution in Kentucky, listed only two collections from the basin and experssed the need for further studies to describe accurately the distribution of these insects in the state. Macroinvertebrates collected at four Licking River stations were listed by the Kentucky Nature Preserves Commission (1979).

Post-impoundment benthic studies of Kentucky reservoirs have concentrated on the reservoirs themselves, rather than the tailwaters (Bates, 1962; Charles and McLemore, 1973). Studies in Montana by Gore (1977) related the regulation of a reservoir to macroinvertebrate community changes downstream. He constrasted the zone of cold hypolimnetic discharge near the reservoir, dominated by the molluscs Physa and Sphaerium, to the warmer zone farther downstream, dominated by the caddisfly larva Cheumatopsyche; significant population changes were observed with increased summer temperatures and reduced flow. Ridley and Steele (1975) reviewed the effects of river impoundments on biota. They found that temperature changes, reduction of peak flows, and changes in the quantity and nature of suspended material (including the introduction of lacustrine plankton into the lotic system) caused "irrevocable" changes in rivers downstream from impoundments.

Macroinvertebrates as Indicators of Environmental Stress

Dusoge and Wisniewski (1976) found that a temperature rise of only 2°C significantly affected the benthic community of a river. Diversity indices were relatively low in streams stressed by channelization and sedimentation in Indiana (McCafferty, 1978). Presence or absence of certain species or higher taxa were often convincing evidence of stress in a stream ecosystem (Hawkes, 1962; Godfrey, 1978).

Ball and Bahr (1975) considered benthic diversity a sensitive pollution indicator. According to Wilhm (1975), macroinvertebrates are more suitable indicators than algae, diatoms, protozoa, or fish because of their lack of mobility and ease of sampling and identification. He considered pollution assessment primarily a biological problem.

Not all studies have shown correlations between water quality and benthic communities. Friberg, et al. (1977) found few correlations between environmental variables and community parameters in south Swedish streams. Sampling method, area sampled, time of year, and taxonomic level of identification influenced macroinvertebrate diversity index values in South Wales; depth and duration of sampling had no influence (Hughes, 1978).

Distribution of Stream Macroinvertebrates

The natural distribution of benthic organisms must be considered in a study of this type. Areal and temporal distribution of benthic organisms is influenced by a number of factors other than water quality. Clinger (1974) and Minshall and Minshall (1977) found species diversity higher in riffles than in pools, with few species occurring in pools that were not found in riffles. Microhabitat and temporal distribution can separate closely allied species (Minshall, 1954). Current, substrate and natural chemical factors influence benthic insect distribution (Rabeni and Minshall, 1977; Minshall and Minshall, 1978). Kovalak (1978) found little difference in diurnal and nocturnal densities of benthic organisms on natural and artificial substrates.

Friberg, et al. (1977) found that diversities did not correlate from season to season or between different locations in the same stream.

Sample Analysis

There is considerable disagreement among biologists in the matter of macroinvertebrate data analysis. The Shannon-Weaver index of diversity, $\bar{d}$, has been used by many investigators, e.g., Barrett (1977); McCafferty (1978); Minshall and Minshall (1977), and is probably the parameter closest to a standard measure of community structure. Wilhm (1968) suggested the substitution of biomass units (weight of organisms) for number of individuals per species in the computation of diversity.

Several authors have criticized the concept of species diversity, or found that diversity indices had little descriptive value in their studies. Clinger (1974) applied three different indices to data from Licking River pools and riffles and obtained widely varying results. Cummins (1975) recommended the use of "functional ecological groups" rather than species diversity. He recognized four of these groups: grazers and scrapers; shredders; collectors (filter and deposit feeders); and predators. Godfrey (1978) interpreted a community by species presence or absence and tolerance information from published sources. Hurlbert (1971) called species diversity a "non-concept" and recommended its abandonment. The United States Environmental Protection Agency (USEPA, 1973) encouraged the use of equitability, e, in conjunction with $\bar{d}$, and cited studies in the southeastern United States in which $\bar{d}$ lacked sensitivity where e was quite sensitive to stream pollution.

Thus, benthic macroinvertebrate data interpretation is complex, calling for the use of several analyses of the same data, and a measure of subjectivity. The subject is further complicated by the large number of environmental variables involved, and the inadequacy of standard sampling methods (Usinger, 1968; Hynes, 1970).

Physical and Chemical Factors

Among the environmental factors considered in this study were temperature fluctuations, flow regulation, and concentrations of dissolved metals and hydrogen sulfide. Although slight changes in average temperature can affect invertebrates communities (Dusoge and Wisniewski, 1976), most studies of stream temperatures have concentrated on thermal pollution, rather than temperature depression.

Siegfried and Knight (1977) found that hydropsychid caddisfly larvae and larger organisms were more susceptible to flood-scouring than swimmers or small forms. Thus, the elimination of flood peaks would favor the former.

Little is known about benthic organism tolerance to dissolved iron and manganese. In a study of isolated chitin, Yoshinari and Subramanian (1976) found that Fe^{++} and Mn^{++} were absorbed completely by chitin from solutions of up to 16 mg/ℓ of these elements. Whitton and Say (1975) reported that there had been few studies of metal toxicity in running waters. They cited studies showing _Simulium latipes_, a black-fly larva, in water with high lead concentrations; manganese enrichment in algae up to 250,000 times the ambient concentration; and zinc and cadmium enrichment in aquatic insects by factors of 90-1,400 times the ambient. Metals toxicity data for a few aquatic invertebrates were summarized by Bond and Straub (1973).

Complexing and catalysis of manganese reduction and oxidation by organic compounds in natural waters are known (Ingols and Wilroy, 1963; Hem, 1964). Ingols and Wilroy (1962) also studied the behavior of manganese downstream from a Georgia reservoir and discovered that the element "leap-frogged" (i.e., was alternately precipitated and redissolved) 25 miles downstream in three years. Since oxidized iron and manganese precipitate conspicuously in the area immediately downstream from Cave Run Lake, this process may occur there also.

Hawkes (1962) found that the stonefly *Perla* and the mayfly *Ecdyonurus* were resistant to hydrogen sulfide where dissolved oxygen saturation existed.

Most of the information on benthic organism tolerances has come from field studies of polluted or stressed streams and has not related organism responses to specific environmental parameters. For example, the caddisflies *Cheumatopsyche* and *Hydropsyche* and the black-fly *Simulium* were consistently found in recovery zones where oxygen was plentiful, but where mayflies and stoneflies were absent (Hawkes, 1962; Toms, 1975; Bloesch, 1977). Most published information on environmental tolerances of macroinvertebrates rated species or higher taxa as either tolerant, facultative, or intolerant. The USEPA (1973) listed many common benthic organisms with tolerances expressed in this way.

CHAPTER III

MATERIALS AND METHODS

Sources of Data

Aquatic macroinvertebrates were collected at five Licking River stations and one station on a tributary (Figure 1; Table I). Additional data on macroinvertebrates were obtained from earlier studies by Clinger (1974), Batch (1979) and Goodwyn (1971).

Water quality data collected for the USCE monitoring program were obtained from computer files and selectively summarized. Streamflow data were extracted from records of the United States Geological Survey (USGS).

Station Locations

The six sampling stations are described in Table I. Stations I, II, and III coincided with established USCE monitoring stations, where water quality data for several years were available and some macrobenthos samples were collected before this study was initiated. Stations IV, V, and VI were chosen to determine community changes with increasing distance downstream from Cave Run Dam.

Stations I and II, upstream from the reservoir, were included to give an idea of the condition of the

TABLE I

STATION DESCRIPTIONS

Station	Latitude Longitude	Location	Substrate	Sample Type and Dates
I	37°55'56" 83°15'44"	Licking R: riffle one km downstream from West Liberty, Ky.	Rubble, gravel, sand, detritus	Surber: Aug. 1977
II	37°57'31" 83°16'49"	Elk Fork: riffle two km upstream from mouth	Rubble, gravel, detritus	Surber: Aug. 1978, Aug. 1979
III	38°06'57" 83°33'32"	Licking R: riffle 2.9km Downstream from Cave Run Dam	Rubble, shaly gravel, sand, detritus, macrophytes	Surber: Aug. 1977, Aug. 1978, Apr., June, Aug., Oct. 1979 Qualitative: Nov. 1978, Apr., June, Oct. 1979
IV	38°08'44° 83°35'00"	Licking R: riffle 9.1km downstream from Cave Run Dam (immediately above mouth of Triplett Ck.)	Shelving-bedrock, gravel, rubble	Surber: Apr. 1979 Qualitative: Apr., Aug. 1979

Table I. Continued.

Station	Latitude Longitude	Location	Substrate	Sample Type and Dates
V	38°08'45" 83°34'03"	Licking R: riffle 9.2km downstream from Cave Run Dam (immediately below mouth of Triplett Ck.)	Rubble, gravel, sand	Surber: Apr. 1979 Qualitative: Apr., Aug. 1979
VI	38°10'37" 83°37'04"	Licking R: run 35.4km downstream from Cave Run Lake	Rubble, gravel, sand	Qualitative: Apr. 1979

river and one of its tributaries in an area free from the effects of reservoir releases. These two stations cannot be considered strict controls, however, because of their distances from the downstream stations, the influence of a trickling-filter sewage treatment plant one km upstream from Station I, and acid stripmine drainage in Elk Fork watershed above Station II.

Quantitative Sampling

Quantitative benthic samples were taken from riffles with a Surber square-foot (.09m^2) stream bottom sampler with a 30-mesh net. To obtain a relatively large number of organisms and reduce the influences of varying substrate, microhabitat and flow, five to eight square-foot (0.46-0.7m^2) subsamples were collected during each sampling event, and the subsamples composited. The subsamples were taken at invervals across the stream to approximate a cross-section of the stream bed. The substrate was sampled to a depth determined by its composition: from its surface on bedrock to about fifteen centimeters (cm) in less consolidated material.

The samples were preserved by topping-off the glass sample jars by diluting a 37% formaldehyde solution to a concentration of approximately 10% formalin.

A small amount (1-2 mg/ℓ) of Rose Bengal stain was added to most of the samples before preservation to aid in sorting (separating organisms from sand, gravel and detritus).

Sorting of quantitative samples was done in the laboratory. The sample jars were emptied into a 30- or 35-mesh sieve and washed with water to remove formalin, silt and fine debris. The sieve contents were transferred to sorting pans, where samples without Rose Bengal stain were sorted by examining all collected material under a stereoscopic dissecting microscope. Stained samples were sorted directly from the pans, with the occasional aid of a microscope. After sorting, the organisms were grouped into rough taxonomic categories and preserved in 70% ethanol for further identification. References used for identification are listed in Appendix B.

Qualitative Sampling

Various methods were employed for qualitative sampling. A wooden-handled rectangular net with one-millimeter mesh was used for collecting along banks, under logs suspended in the stream, in emergent macrophytes and where water depth and/or velocity prevented use of the Surber sampler. Kick samples were taken using both the rectangular net and the Surber sampler with the frame folded back. Large mussels were collected by hand-picking from the stream bottom in riffles, runs and adjacent pools. Qualitative samples were preserved and sorted in the same manner as quantitative samples.

Water Quality Data

Field measurements of temperature, dissolved oxygen, pH and conductivity were made using equipment manufactured by Hydrolab, Inc.; the equipment was calibrated using standard procedures. All other water quality analyses were performed in USCE laboratories in accordance with Standard Methods for the Examination of Water and Wastewater (1971).

Data Analysis

Quantitative macroinvertebrate data were subjected to various analyses. Species diversity, equitability, and number of organisms per m^2 (density) were calculated for each composite sample, as recommended by USEPA (1973; see Tables II and III and Figure 2). Qualitative and quantitative data were combined for determination of species presence or absence and distribution by tolerance groups (Figure 3; Appendix A).

Separate monthly means for pre- and post-impoundment water quality and streamflow data were calculated and the significant parameters presented graphically in Figures 4 and 7 through 12.

CHAPTER IV

RESULTS

Pre-Impoundment Studies

In a qualitative downstream survey of the Licking River during Cave Run Dam construction, Goodwyn (1971), characterized the biota as pollution-intolerant, with hydropsychid caddisfly larvae and mayfly nymphs of the genus *Stenonema* abundant. In quantitative samples taken by Clinger (1974) at fourteen riffle stations on the portion of the river now impounded, *Stenonema*, Cheumatopsyche, and chironomid midge larvae were the dominant benthic organisms. These findings, together with data collected at upstream stations during this study, established the general nature of pre-impoundment macroinvertebrate communities in the Cave Run Lake vicinity.

Macroinvertebrates

Macroinvertebrate data are summarized in Tables II and III, Figures 2 and 3, and Appendix A. Tables II and III and Figures 2 contrast community composition immediately downstream from the dam (Stations III and IV) with the upstream stations (I and II), and show the recovery downstream from the mouth of Triplett Creek

TABLE II

MACROINVERTEBRATE COMMUNITY COMPOSITION UPSTREAM (STATIONS I AND IV) AND DOWNSTREAM (STATIONS III AND V) FROM CAVE RUN LAKE BASED ON QUANTITATIVE SAMPLES

Station	I	II	III	V
Taxon	Organisms per square meter			
Ephemeroptera	35	86	0	11
Odonata	2	2	0	0
Plecoptera	3	2	0	0
Hemiptera	0	1	0	0
Coleoptera	2	8	1	9
Trichoptera	14	20	88	3
Megaloptera	2	0	1	0
Diptera	97	24	34	45
Crustacea	2	3	2	3
Pelecypoda	0	0	4	2
Gastropoda	0	0	1	0
Oligochaeta	34	0	5	6
Nematoda	9	1	0	0
	200	147	136	79
	Percentage of total sample			
Ephemeroptera	18	59	0	14
Odonata	1	1	0	0
Plecoptera	1	1	0	0
Hemiptera	0	1	0	0
Coleoptera	1	6	1	11
Trichoptera	7	14	64	4
Megaloptera	1	0	1	11
Diptera	49	17	25	57
Crustacea	1	2	1	4
Pelecypoda	0	0	3	3
Gastropoda	0	0	0	0
Oligochaeta	17	0	4	8
Nematoda	5	1	0	0

Columns do not add to 100% because of rounding.

TABLE III

SUMMARY OF MACROINVERTEBRATE DATA
UPSTREAM (STATIONS I AND II) AND DOWNSTREAM
(STATIONS III-IV) FROM CAVE RUN LAKE

Station	Area Sampled	Density		Indices		Taxa Collected		
	m^2	n	n/m^2	$\bar{d}$	e	N_1	N_2	N_3
I	0.65	129	198.3	3.55	0.55	21	-	21
II	1.12	163	146.0	3.33	0.49	24	-	24
III	3.72	510	137.1	2.18	0.26	28[a]	16	38
IV	0.74	7	9.4	-[b]	-	6	16	20
V	0.65	51	78.3	3.54	0.69	17	11	25
VI	-	-	-	-	-	-	18	18
Totals	6.88	860	125.0(mean)			55	35	76

n = number of organisms; $\bar{d}$ = index of diversity; e = equitability; N_1 = number of taxa in quantitative samples; N_2 = taxa in qualitative samples; N_3 = taxa in combined samples.

[a]Samples from Station III included at least two species each of Cheumatopsyche and Simulium. Since these could not be separated accurately, each genus has been considered as one taxon in calculations. This lowers $\bar{d}$ and e; however, even in the extreme case of four species of equal numbers, $\bar{d}$ = 2.94, e = 0.35, still below other stations.

[b]Too few organisms were collected to calculate meaningful indices.

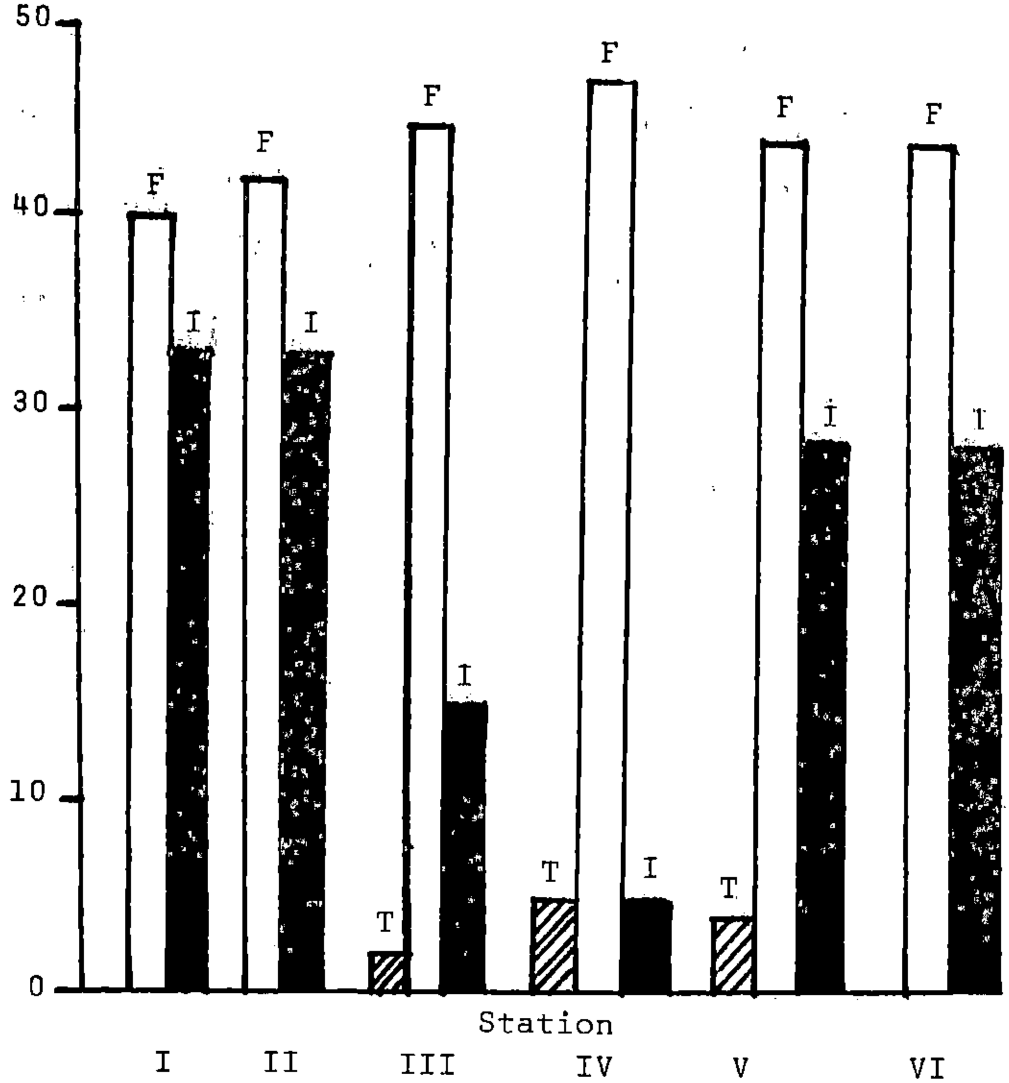


Figure 2. Percentage of total taxa collected at each station according to tolerance groups. Quantitative and qualitative samples combined. T = tolerant; F = facultative; I = intolerant.

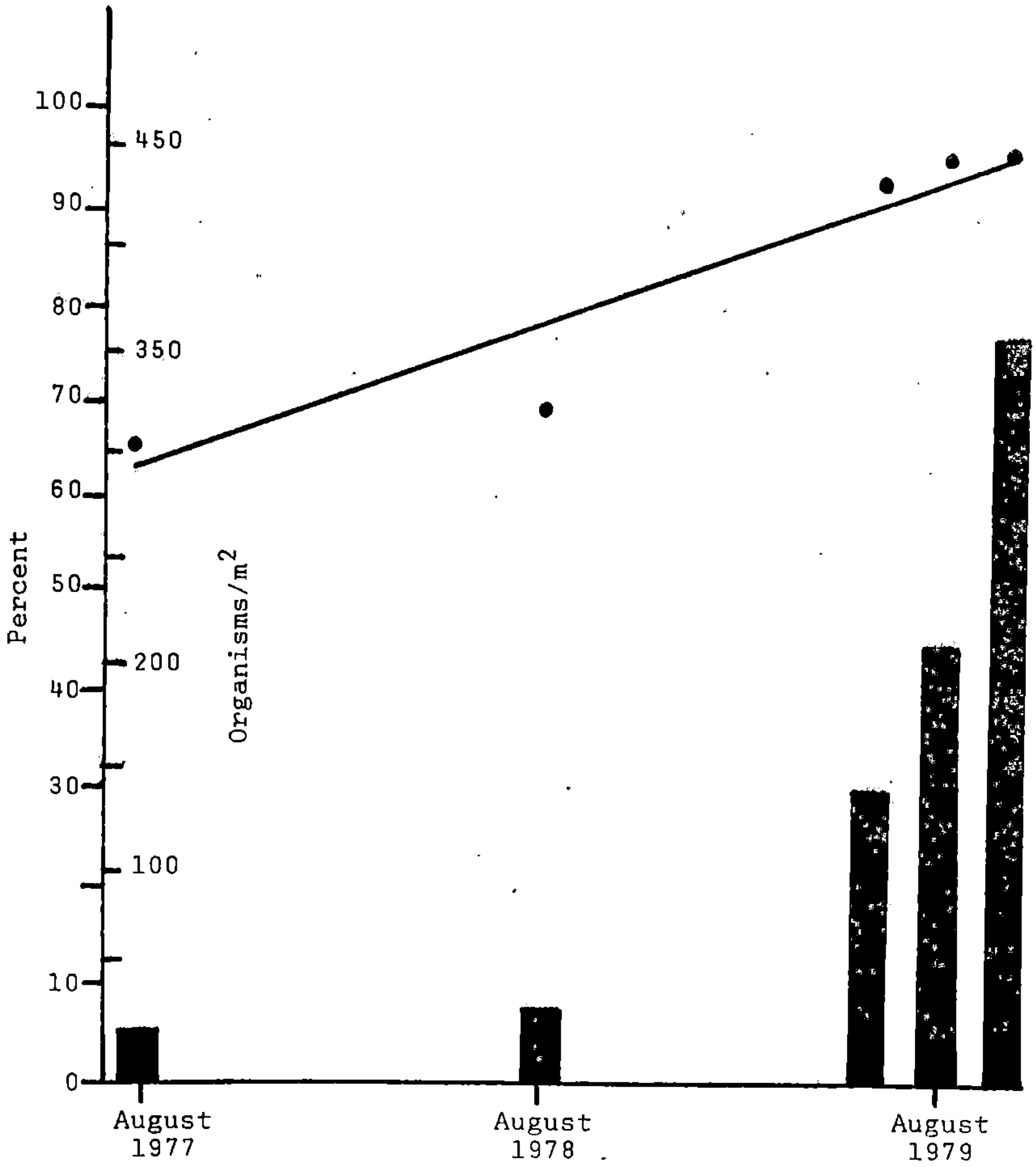


Figure 3. Combined dominance of Diptera and Trichoptera at Station III. Bars are numbers per m^2, dots show increasing proportion of these groups in quantitative samples; slope plotted by method of least squares.

(Stations V and VI). Figure 3 depicts the combined population growth of dipteran and trichopteran larvae at Station III during the period of study. Appendix A is a list of the organisms collected at each station.

At Station I, upstream from the reservoir, the dominant benthic organisms were the mayflies _Stenonema_ and _Baetis_, and oligochaete worms of the family Naiadidae. All of the major aquatic insect orders were present, except for Hemiptera (Hemipterans seldom frequent riffles and usually are not taken in square-foot samples). No pollution-tolerant species were collected at this station (Figure 2), despite sewage treatment plant discharge one km upstream. An October 1975 Surber sample from the river near Station I showed similar community composition, except for the relative abundance of the stoneflies _Nemoura_ and _Allocapnia_ (USCE water quality file date).

At Station II, the other upstream reference (on Elk Fork), _Stenonema_ was numerically dominant, with _Cheumatopsyche_, _Simulium_ and the mayfly _Ephoron_ also well-represented. Oligochaetes were absent.

At Station III, downstream from the dam, the attached, filter-feeding _Cheumatopsyche_, _Simulium_ and _Rhenotanytarsus exiguus_ (a midge larva) were most abundant. Mayflies and stoneflies were absent. (A single Stenonema nymph collected in the August 1977 sample cannot be considered evidence of a viable mayfly population at this location.)

From 1977 through 1979, samples from Station III showed a trend toward increasing dominance by dipteran and trichopteran larvae (Figure 3), with no evidence of colonization by mayflies and stoneflies. Data from the April 1979 sample have been omitted from Figure 3; this sample was taken after an extended period of high flow, and so few organisms were collected that the data were not reliable for quantitative measurement of community composition.

Qualitative data from Station IV showed a community similar to that at Station III, with mayflies and stoneflies absent. The quantitative sample from this station was taken in April 1979, after the high-flow period; population density was very low (Table III).

Station V was located about 30m downstream from Station IV, where Triplett Creek, the first major tributary downstream from Cave Run Dam, joins the Licking River. A quantitative sample taken here on the same day as that at Station IV (after high flow) showed community composition comparable to the upstream stations, although density was rather low (Table III). Four species of mayflies, including three species of

Stenonema, were collected here (Appendix A).

Only qualitative sampling was done at Station VI, where the water was too deep for Surber samples. Mayflies were present at this station, and one stonefly was collected.

At Stations III through VI, the large unionid mussels were important members of the benthic community. This study did not include quantitative collection of the unionids, which requires special techniques and equipment; however, representative samples were obtained using qualitative methods. Eight species of living mussels and the shell of a ninth species were collected at Station III, eight species at Station IV, four species at Station V, and twelve species at Station VI (Appendix A). The common mucket, *Actinonaias carinata*, was the most abundant mussel at all downstream stations. The lady-finger mussel, *Elliptio dilatatus*, and the three-ridge mussel, *Amblema plicata*, were collected at Stations IV, V and VI, and were plentiful at Station VI. The fingernail clam *Sphaerium* was collected only at Stations III and IV, suggesting that this organism is favored by reservoir discharge (also see Gore, 1977). The giant washboard mussel, *Megalonaias gigantea*, collected at Station VI, apparently had not been collected previously from the Licking River.

Diversity and equitability were much lower at Station III than at Stations I, II and V, where indices were closely comparable (Table III). Apparent density differences between stations probably were not significant, because the impoverished samples of April 1979 lowered downstream (Stations III, IV and V) densities disproportionately. In general, density variations among samples were too large for firm conclusions to be drawn, except that numbers at Station III increased with time, as the filter-feeding organisms became more dominant (Figure 3). Densities were higher than the 62.6 organisms per m^2 reported for the series of riffle samples by Clinger (1974); this probably reflects the less-inclusive sampling method used in his study.

Interpretation of macroinvertebrate data by tolerances (Godfrey, 1978) and functional ecological groups (Cummins, 1975) is difficult because of incomplete and ambiguous published information. Although Figure 2 reflects clear differences between stations, tolerance information was not found for 25-40% of the taxa. Much available information is equivocal (e.g., USEPA, 1973); therefore, some subjectivity was applied to the preparation of Figure 2. For the purposes of this study, organisms that are found consistently in clean water, but which thrive in stressed or moderately polluted zones, were considered facultative (e.g., *Cheumatopsyche*). Intolerant organisms were those rarely found in stressed habitats (*Acroneuria*, *Isonychia*); tolerant organisms were those rarely found outside of polluted or stressed zones (Lumbriculidae). Tolerance information for most of the taxa was taken from USEPA (1973); several references from the taxonomic (Appendix B) and ecological (e.g., Hynes, 1970) literature were also consulted.

Community description by functional ecological groups can be accomplished only in very general and qualitative terms. Although most macroinvertebrates are adapted to certain types of substrates and specific food-gathering techniques, their preferences often are not exclusive. Many filter-feeders and grazers are opportunistic feeders and will take prey, and even seek it out (Hynes, 1970). Furthermore, information on the feeding habits of many macroinvertebrates either is unavailable, or has been based on morphology rather than field observations or experimental work.

The tailwater community was dominated by the attached filter-feeders *Cheumatopsyche*, *Simulium*, and *R. exiguus*, all of which require a clean substrate and suspended food particles of certain sizes (Hynes, 1970).

These organisms also are favored by flood control, because they are not swimmers and tend to be dislodged when strong currents disturb the substrate (Siegfried and Knight, 1977).

Detritus-feeders, grazers, and predators were scarce in the area affected by reservoir discharge (Stations III and IV), although detritus showing evidence of shredding was plentiful, and rubble was well-covered with diatoms and algae. Fish and crayfish, respectively, were probably the most important predators and detritus-feeders in this zone.

Flow Regulation

Impoundment of the Licking River caused important changes in downstream flow regimes. Water stored during flood periods reduced peak flows, and gradual release of storage resulted in abnormally extended periods of high flow. Extremely low flows were eliminated by augmentation.

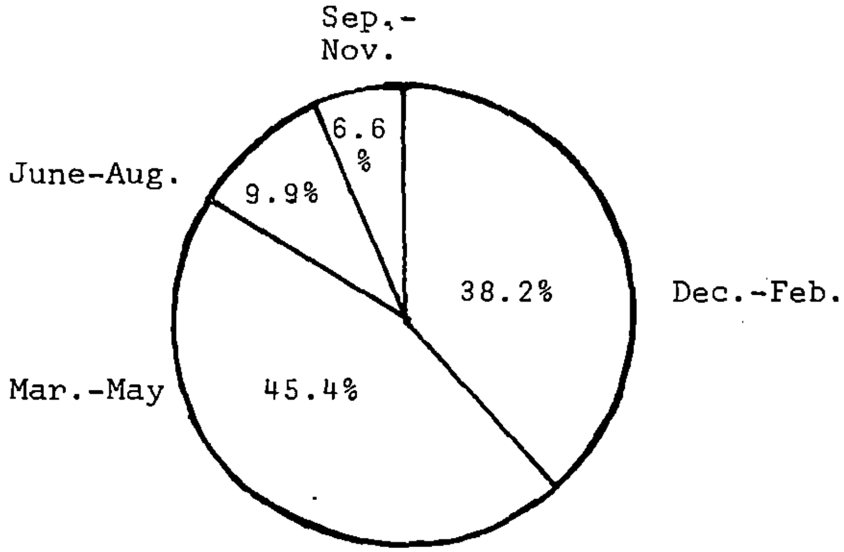
Scouring of stream channels during floods causes reductions in benthic fauna (Siegfried and Knight, 1977); the samples taken in April 1979 indicated that extended high flows, although well below flood levels, can have similar effects. The release of reservoir flood storage from a series of winter storms in 1978-1979 resulted in high downstream discharge throughout most of the period from mid-December 1978 to late April 1979.

The natural seasonal variation in river flow was altered by impoundment (Figure 4). Mean monthly discharges for December through February and June through August approximated pre-impoundment levels. However, the storage of water during the spring months caused lower mean flows from March through May, and autumn reservoir drawdown increased mean flows from September through November (Figure 4). It is not clear what effect, if any, this phenomenon had on macroinvertebrate populations, although it is conceivable that organisms adapted to the natural periodicity of streamflow might be stressed by systematic changes in that periodicity.

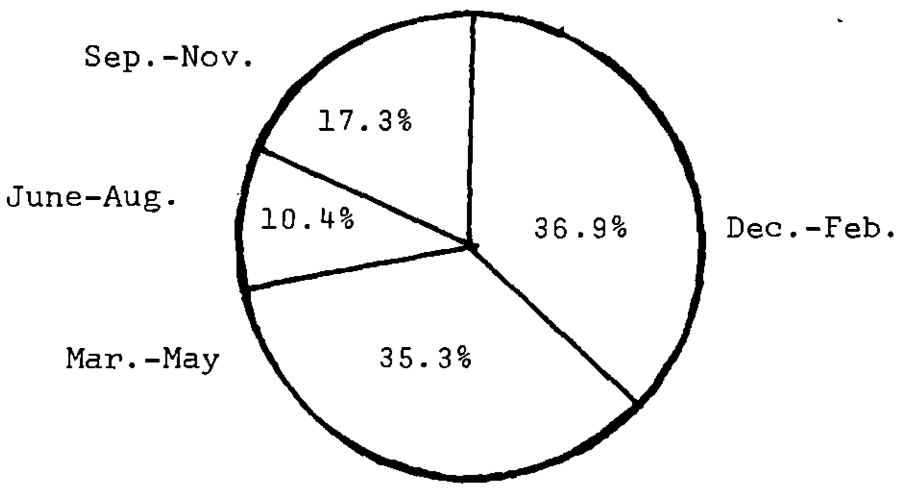
The other important element of flow regulation is low-flow augmentation. Since low river flows are known to cause massive drift of invertebrates (Gore, 1977), augmentation may change community composition significantly.

Water Quality

A number of changes in downstream water quality resulted from impoundment. Temperature, and concentrations of nitrogen, phosphorus, iron, manganese,



Pre-impoundment



Post-impoundment

Figure 4. Seasonal flow distribution as percentage of total annual discharge, Cave Run tailwater. Pre-impoundment (1968-1973) at top, post-impoundment (1974-1979) at bottom. Data from USGS guage at Farmers, Kentucky.

hydrogen ion, and bicarbonate alkalinity all showed significant differences when compared to upstream and pre-impoundment conditions (Figures 5 through 12).

Some rather extreme temperature fluctuations occurred in midsummer, when the reservoir was stratified and differences between upper- and lower-level temperatures were greatest. Tailwater temperatures in July and August ranged from 13° - 28°C, compared to a range of 18° - 27°C at Station I and 17° - 27°C at Station II. The most intense fluctuations occurred during the summers of 1976 and 1979 (Figures 5 and 6). Autumn temperatures were consistently higher than pre-impoundment norms because of heat conservation in the reservoir. In Figures 7 and 8, monthly mean temperatures from Stations I and II are compared with those at Station III before and after impoundment.

Pre- and post-impoundment maxima, minima and means for several water quality parameters are displayed in Figures 9 through 12. Reductions in downstream concentrations of dissolved and suspended solids, iron, nutrients (particularly phosphorus), hydrogen ion and bicarbonate alkalinity were apparently related to impoundment. Manganese concentrations increased, and ratios of dissolved to particulate iron and manganese were altered (Figure 12).

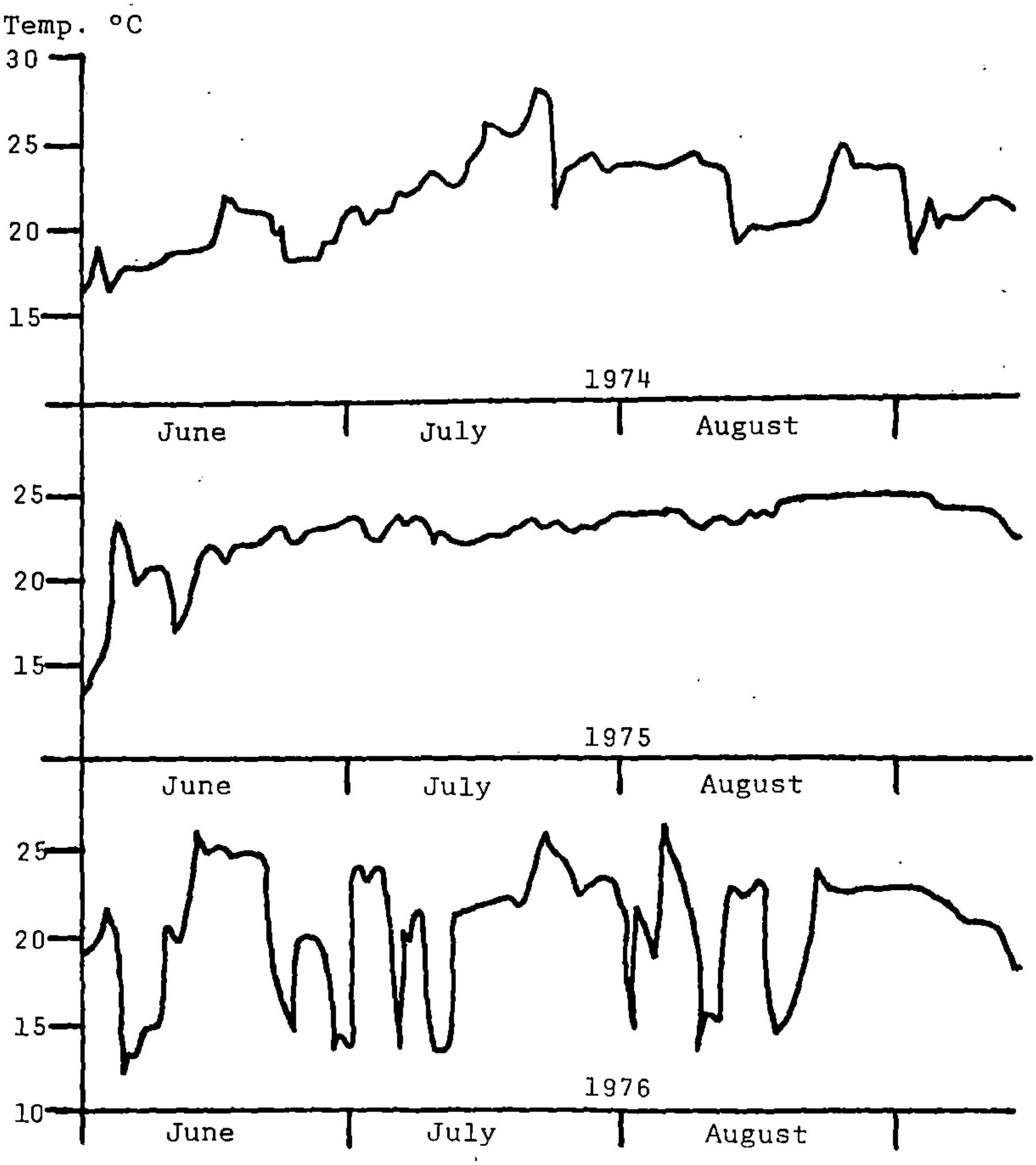


Figure 5. Summer tailwater temperatures, 1974-1976; recorded daily at Cave Run Lake outflow.

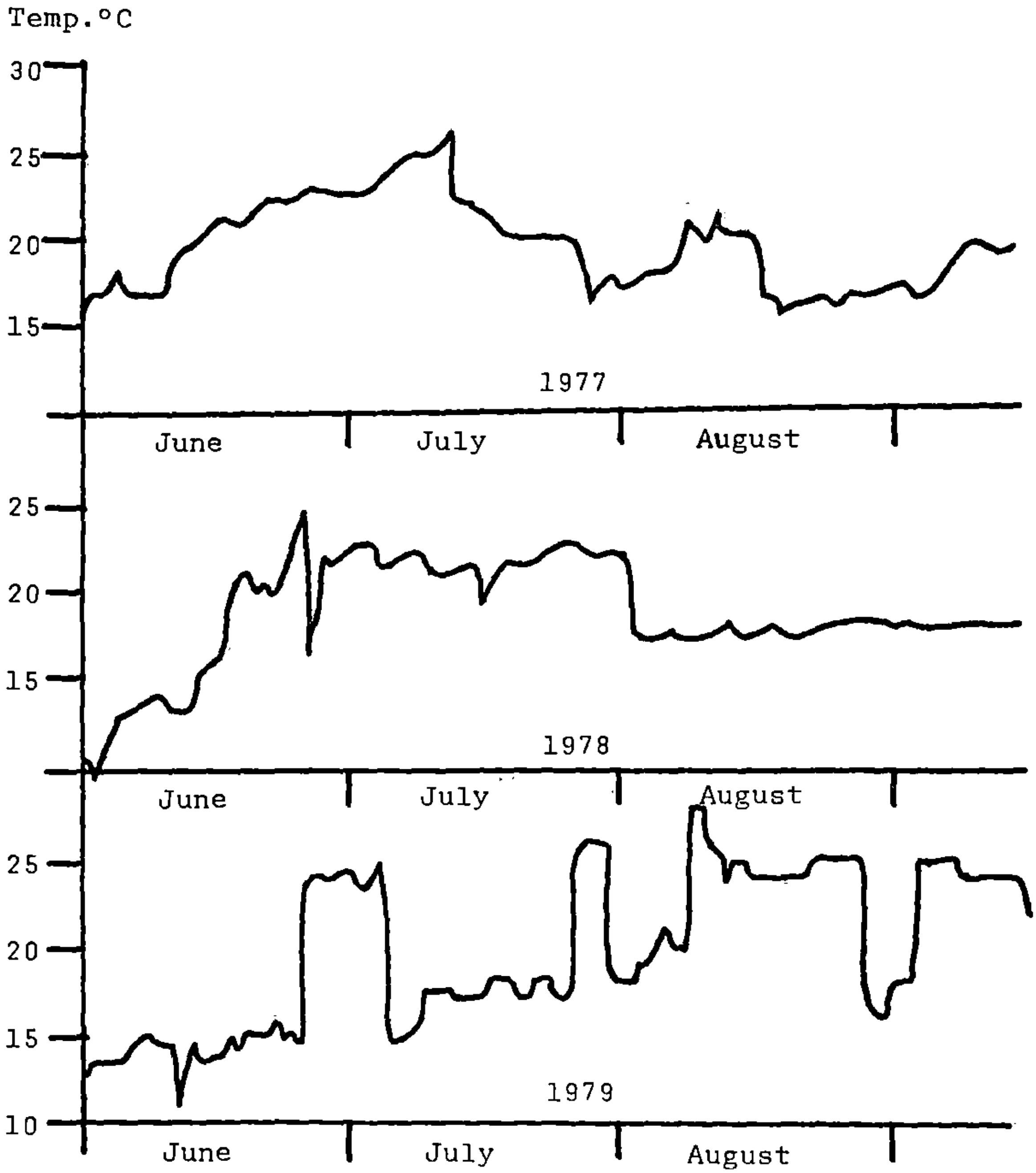


Figure 6. Summer tailwater temperatures, 1977-1979; recorded daily at Cave Run Lake outflow.

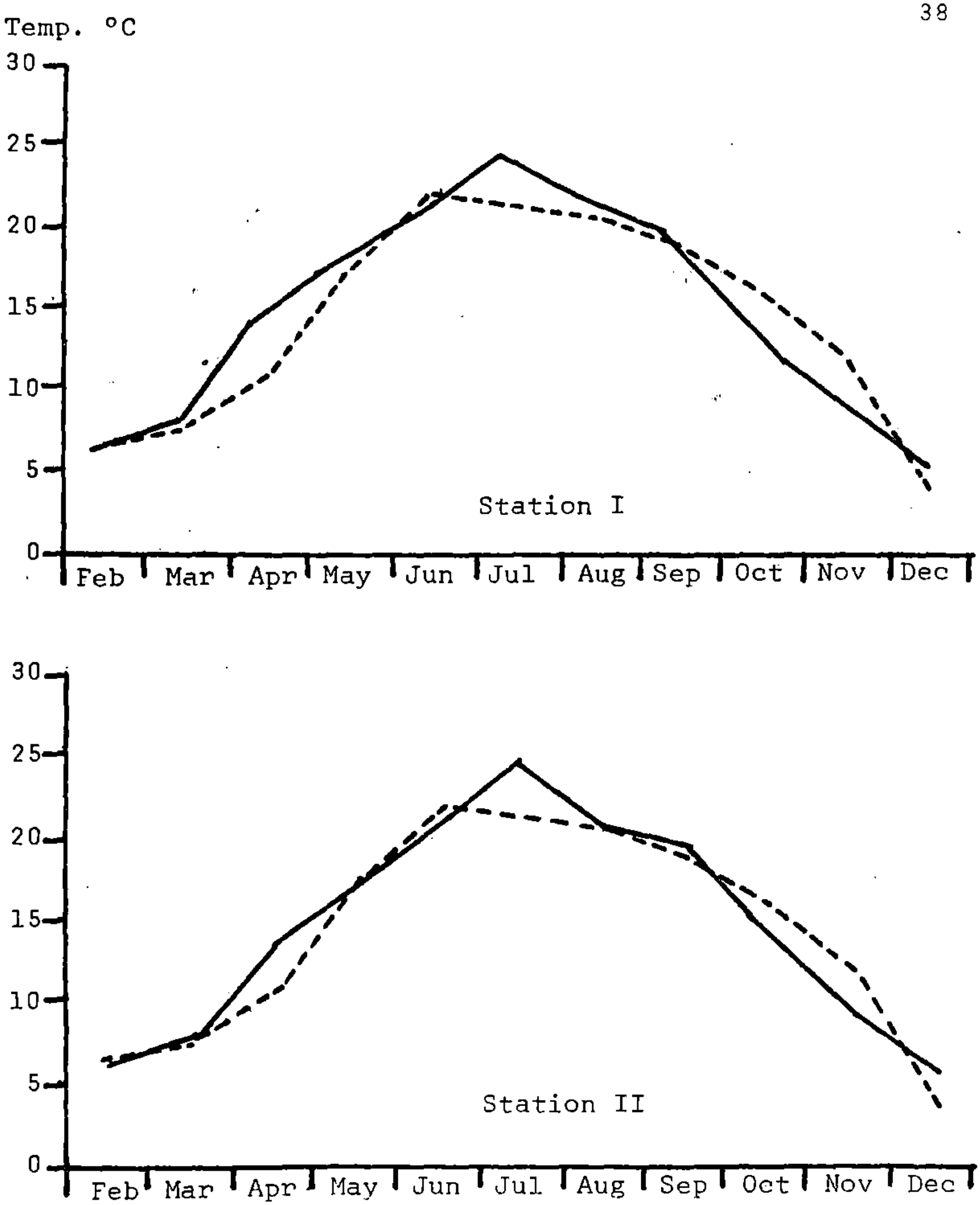


Figure 7. Monthly mean temperatures at upstream stations (solid lines) compared with post-impoundment mean temperatures at Station III (dashed lines). Stations I and II, 1972-1979; Station III, 1974-1979. January temperatures not available.

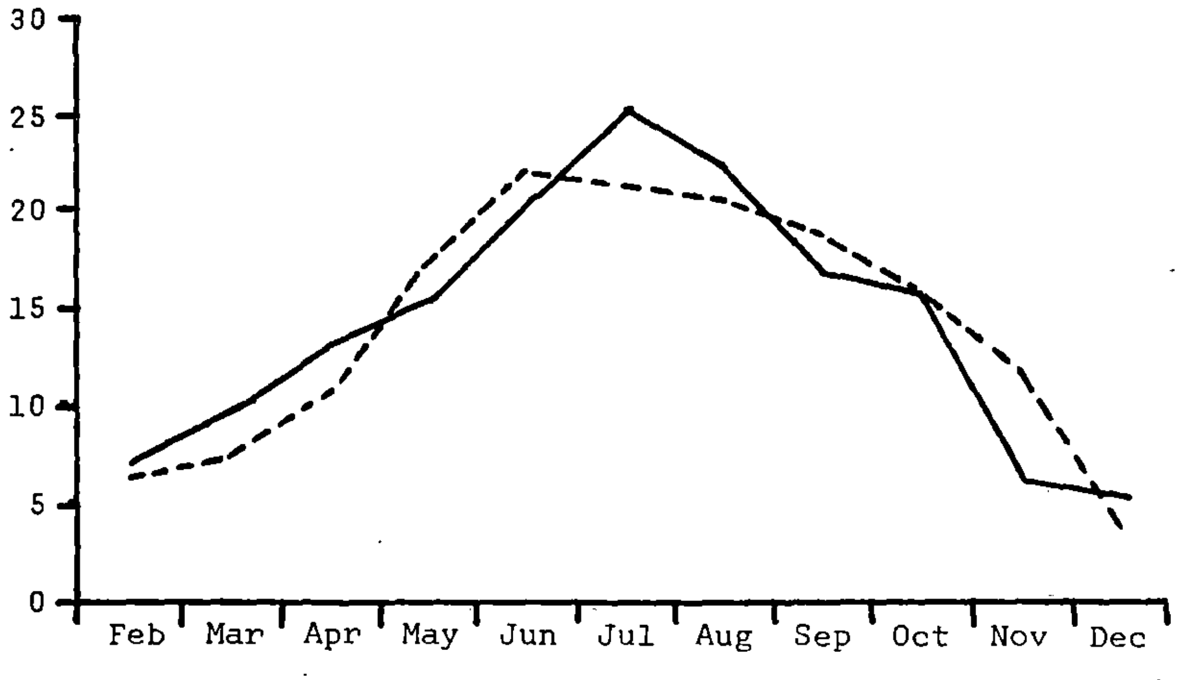


Figure 8. Monthly mean temperatures, Station III. Pre-impoundment (solid line; 1972-1973) and post-impoundment (dashed line; 1974-1979). January temperatures not available.

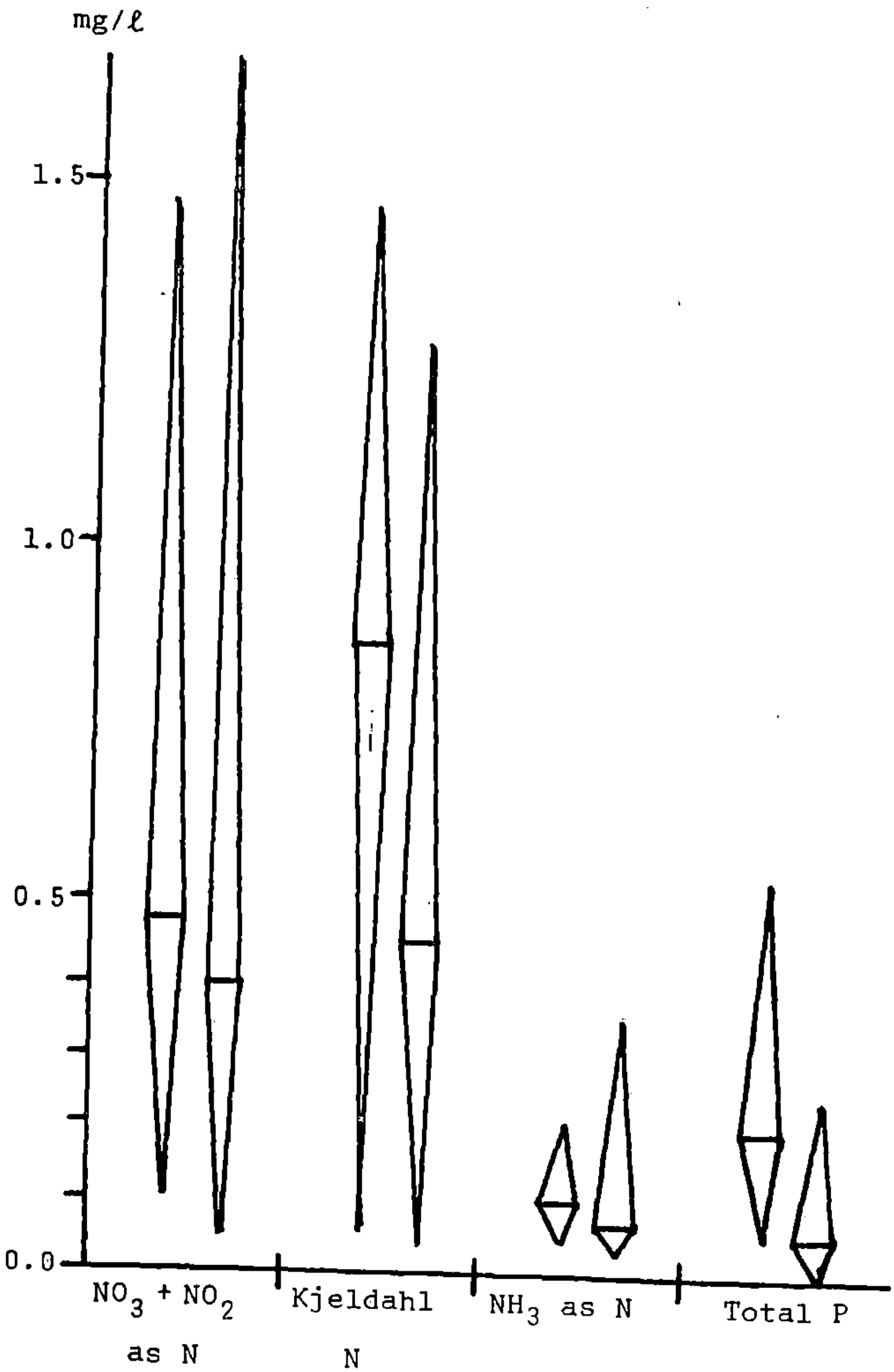


Figure 9. Nutrients: Station III, pre-(left) and post-impoundment (right member of each pair). Maximum, minimum and mean. Exact value distribution not indicated by kite areas.

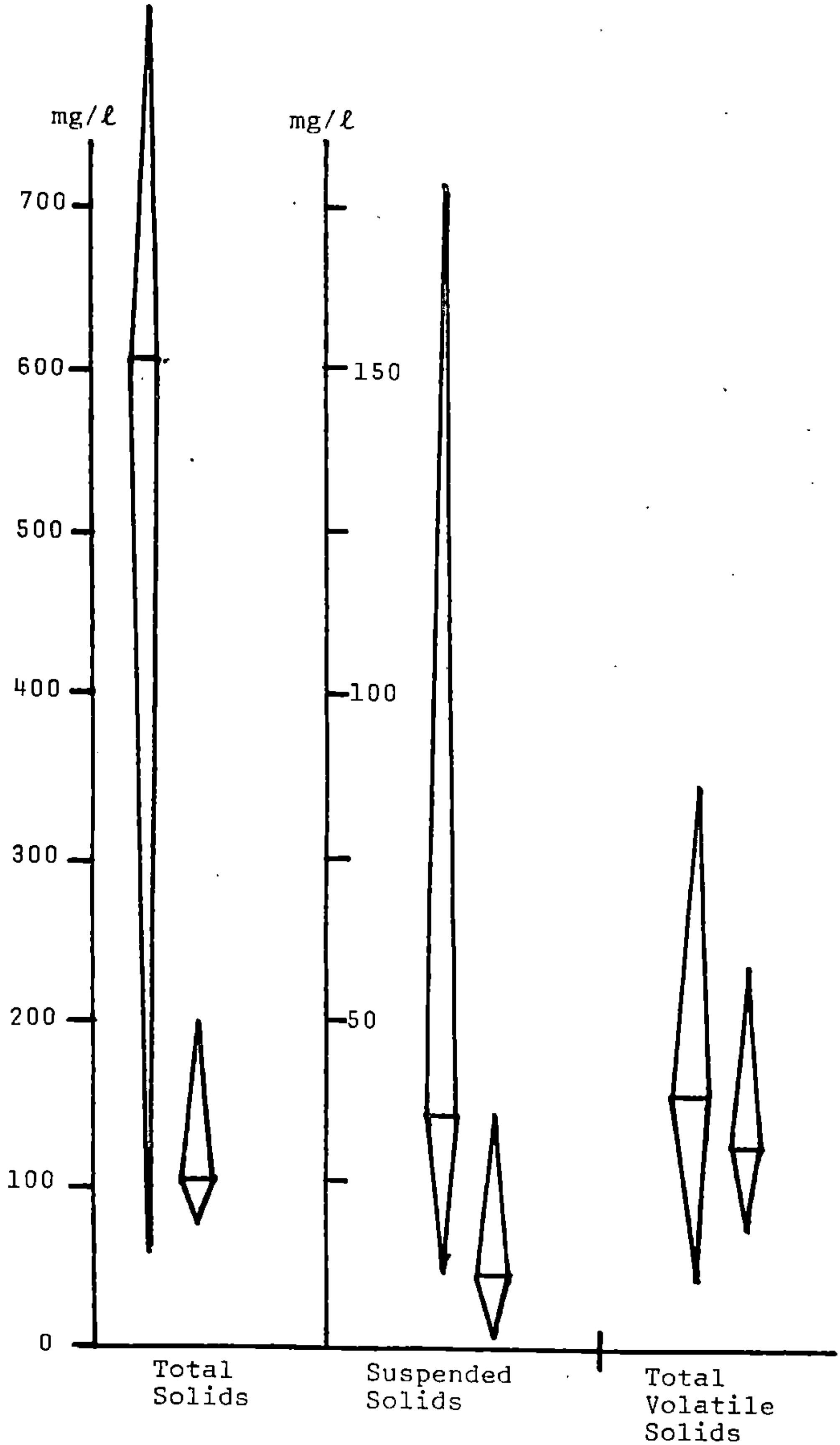


Figure 10. Solids: Station III, pre-(left) and post-impoundment (right member of each pair). Maximum, minimum and mean. Exact value distribution not indicated by kite areas.

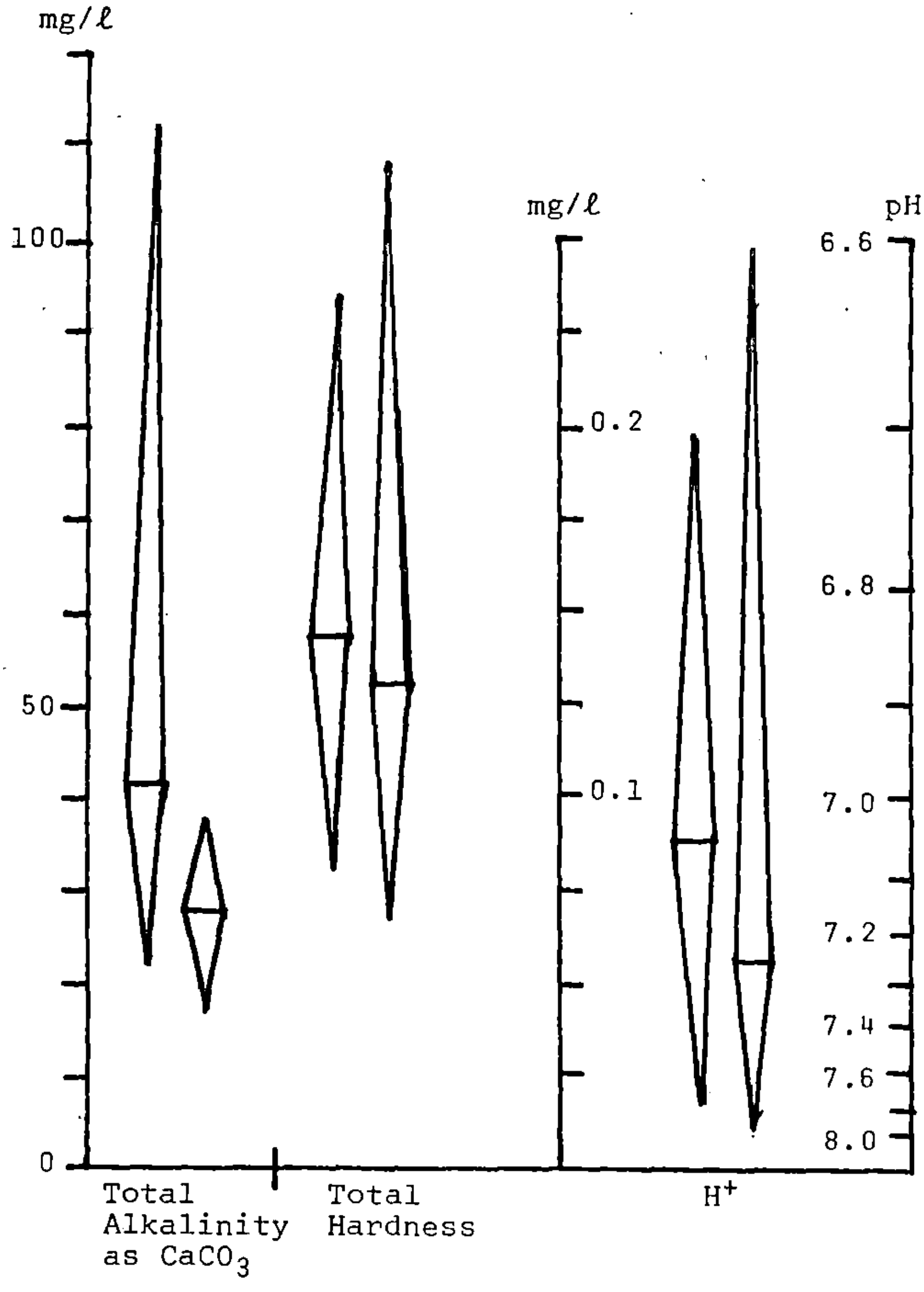


Figure 11. Alkalinity, hardness and pH: Station III, pre-(left) and post-impoundment (right member of each pair). Maximum, minimum and mean. Exact value distributed not indicated by kite areas.

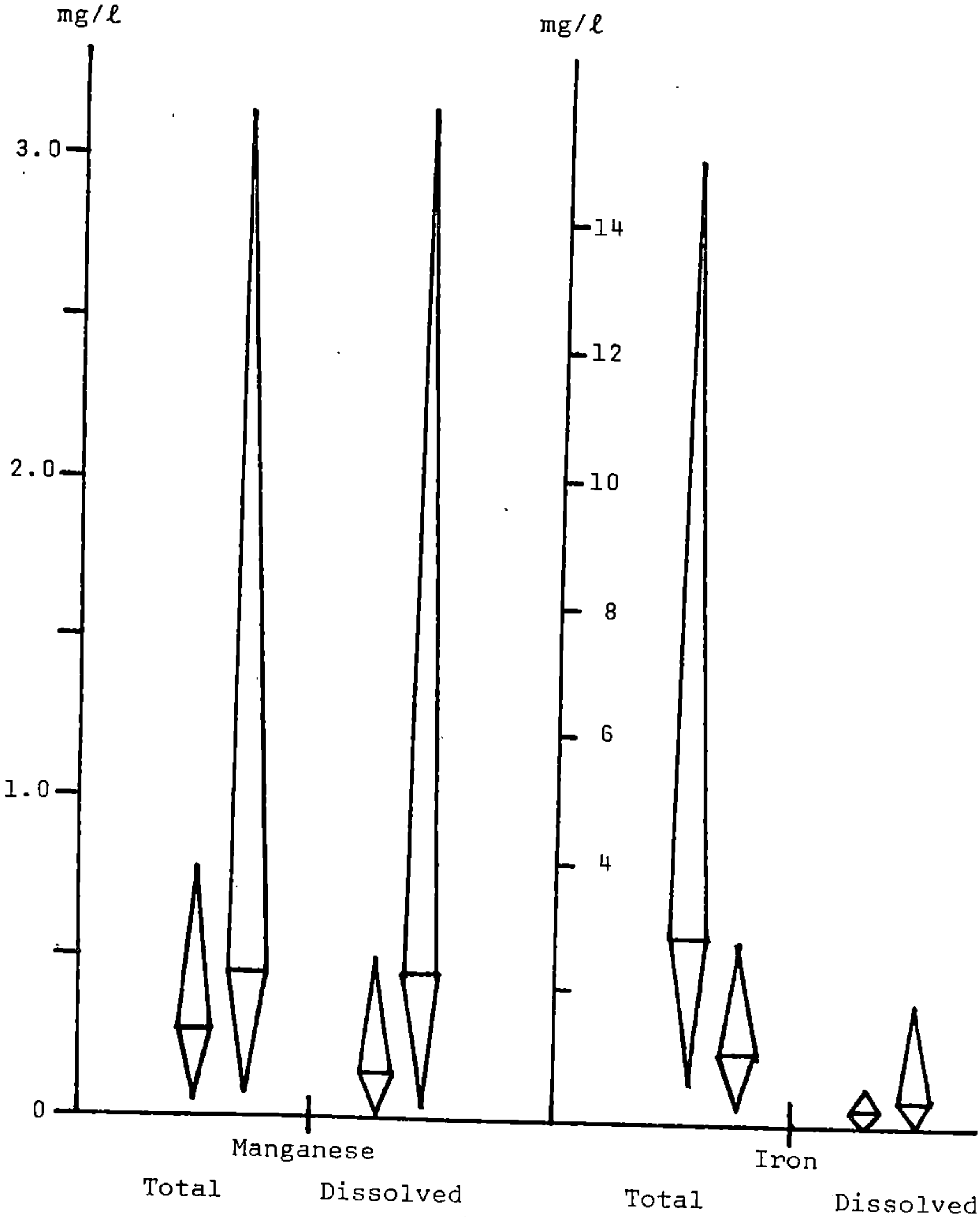


Figure 12. Manganese and iron: Station III, pre-(left and post-impoundment (right member of each pair). Maximum, minimum and mean. Exact value distribution not indicated by kite areas.

Comparisons of inflow and outflow data indicate that solids, phosphorus, nitrogen, iron, and bicarbonate were retained in the reservoir. Physical and chemical precipitation (sedimentation) of solids and iron, and nutrient incorporation in biomass were likely retention mechanisms.

Hydrogen sulfide odor was often apparent during periods of hypolimnetic release. Tailwater concentrations were not measured, but during the summer of 1979, 0.10 mg/ℓ dissolved sulfide was measured near the bottom of the reservoir close to the outlet structure. Hydrogen sulfide odor is noticeable even at this low concentration, and tailwater concentrations probably did not exceed 1.0 mg/ℓ.

The reservoir was sampled near the outlet in August 1979 for a series of trace elements. At a depth of 20m (approximately one meter from the bottom) total aluminum and total lead concentrations were 1.5 mg/ℓ and 0.35 mg/ℓ, respectively. These elements were not present in measurable concentrations at other depths. No significant concentrations of arsenic, cadmium, chromium, mercury, nickel, selenium or zinc were recorded. Fifty percent survival after seven days was reported (Bond and Straub, 1973) for stoneflies (Acroneuria), mayflies (Ephemerella), and caddisflies (Hydropsyche) in water containing 32 mg/ℓ of Pb^{++}. Toxicity information was not found for aluminum.

Dissolved oxygen concentrations at Station III after impoundment ranged from 7.0 mg/ℓ to 12.0 mg/ℓ.

CHAPTER V

DISCUSSION

The stressed macroinvertebrate community downstream from Cave Run Dam resembles that of a moderately polluted stream or a recovery zone in a heavily polluted stream, as described by Toms (1975) and others. Similar conditions have been observed (Gore, 1977), or predicted (Hall, et al., 1974), where reservoir releases were entirely from the bottom. Hall, et al. (1974) predicted the absence of mayflies in the tailwater of a proposed bottom-released reservoir in Wisconsin, based on projected nutrient enrichment and temperature-related disruption of life cycles. Nutrient enrichment is not a factor in the Cave Run tailwater (Figure 9).

Dominance of tailwater communities by filter-feeding organisms is common; this phenomenon usually has been attributed to the presence of lake plankton and detritus (Godfrey, 1978). Other factors favoring such organisms as <u>Cheumatopsyche</u> and <u>Simulium</u> are flow stabilization and a clean substrate for attachment.

The evidence suggests that temperature fluctuations may be a critical factor in the absence of mayflies and stoneflies from the Cave Run tailwater. These organisms, most of which produce one generation per year, often have specific temperature requirements for hatching and nymphal development (Hynes, 1970). Disruption of normal streamflow cycles could interfere with emergence and oviposition for these insects. Hydrogen sulfide, dissolved metals, reduced alkalinity and nutrients may be contributing factors, but probably are not critical.

Localized dissolved oxygen depletion by chemical demand of reduced substances during hypolimnetic releases could be a contributing factor. If oxygen were depleted in a microlayer at the water-substrate interface (perhaps by substrate-catalyzed oxygenation reactions), it would stress flattened organisms like *Stenonema* that have high respiratory rates (Olsen and Rueger, 1968) and depend on this microlayer for respiration. The microlayer would have to be thin enough, or the oxygen depletion subtle enough, not to affect *Cheumatopsyche* and *Simulium*, which respire not more than one or two millimeters farther from the substrate than *Stenonema*.

There is also a possibility that unrecognized and unmeasured products of anaerobic processes, such as organic compounds or trace elements released from reservoir sediments, could contaminate hypolimnetic releases and be selectively toxic to some of the benthic fauna. Whatever the limiting conditions, their influences must be fairly continuous, since recolonization of faunally depleted streams after pollution abatement or return to normal temperatures is rapid (Krumholz and Neff, 1975; Tevesj, 1978; Gore, 1977).

Elimination or substantial reduction of hypolimnetic releases by the proposed modification of the Cave Run outlet structure should be followed by increased diversity and the reappearance of mayflies, and perhaps stoneflies, in the downstream area. However, the conditions favoring filter-feeders will continue to exist, and higher plankton concentrations in all-epilimnetic releases may result in increased populations of these organisms. Cheumatopsyche, Simulium, and R. exiguus are expected to remain plantiful, but Stenonema probably will be competitive, and may become numerically dominant, as was the case before impoundment and at reference stations.

Presence or absence and relative numbers of Stenonema should serve as the most useful benthic indicator in the portion of the river studied. The lumbriculid worms and Sphaerium were present only in the stressed and recovery zones below Cave Run Dam

(Stations III, IV and V), suggesting that these organisms also could be important indicators.

Tailwater community diversity will remain somewhat depressed even after recovery, based on the principle that where an unnatural environment exists, diversity is always lower, and dominance by tolerant (or facultative) organisms is more pronounced (Hynes, 1970).

The augmentation of multi-level discharge capacity under study by USCE may permit year-round temperature regulation which will approximate natural stream conditions. Carefully planned and implemented temperature regulation should be expected to have substantial benefits not only for aquatic insects, but also for fish and mussels. Seasonally warm water in summer, fewer discharges of dissolved metals and hydrogen sulfide, and more diverse aquatic fauna should improve the river's aesthetic value, recreation potential and suitability for water supply.

Evaluation of the effects of outlet structure modification on macroinvertebrates should not require extensive sample collection. With the baseline data available from this and pre-impoundment studies, ocasional qualitative samples should be sufficient to detect any significant changes in community composition.

Again, Stenonema should serve as an excellent indicator.

The lower Licking River contains a diverse mussel fauna: seventeen species were collected during this study (Appendix A), and Batch (1979) reported collection of 25 species from the river in 1969. A large portion of the Lower Licking River meets the mussel "sanctuary stream" criteria of Stein (1971), not having been impounded, subjected to heavy pollution loads, or commercially fished for shells. A comprehensive macroinvertebrate survey of the lower river, including careful collection of mussels, would not only fill a gap in the knowledge of Kentucky fauna, but could qualify portions of the river for protection.

CHAPTER VI

SUMMARY

Macroinvertebrate samples were collected at stations upstream and downstream from Cave Run Lake, and the data compared with pre-impoundment surveys. Water quality and streamflow data were analyzed to determine the effects of impoundment on the downstream environment.

Results showed significant changes in macroinvertebrate communities for several kilometers downstream from the dam. Diversity and equitability were reduced, and increasing numbers of attached, filter-feeding organisms dominated the benthic community. Organisms intolerant of environmental stress were a smaller proportion of the samples in the affected zone. Recovery, indicated by increased diversity and community structure similar to upstream stations, was apparent downstream from the mouth of Triplett Creek.

Summer temperature fluctuations, changes in seasonal distribution of heat and streamflow, and changes in concentrations of dissolved and particulate matter, all impoundment-related, altered the downstream environment.

Two important subjects for further study have been suggested by the present work: a comprehensive survey of the invertebrate fauna of the lower Licking River; and investigation of the precise reasons for the absence of certain taxa downstream from the dam. In investigations into the reasons for the absence of taxa, conjectures concerning microlayer oxygen depletion and trace substances in hypolimnetic releases should be considered.

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APPENDIX A

MACROINVERTEBRATES COLLECTED

Station I

Arthropoda

Insecta

Emphemeroptera

Isonychia serrata
Isonychia sp.
Baetis sp.
Stenonema sp.
Tricorythodes sp.

Odonata

Gomphus lineatifrons

Plecoptera

Acroneuria arenosa

Coleoptera

Stenelmis sp.

Trichoptera

Cheumatopsyche sp.

Megaloptera

Corydalis cornutus

Station I. Continued.

Diptera

Ormosia sp.
Nilothawma sp.
Dicrotendipes sp.
Psectrocladius sp.
Paratanytarsus sp.
Orthocladius sp.
Cricotopus sp.
Trichocladius sp.
Prodiamesea sp.
Chironomidae

Crustacea

Decapoda

Orconectes sp.

Annelida

Clitellata

Oligochaeta

Naiadidae

Nematoda

Station II

Arthropoda

Insecta

Ephemeroptera

Isonychia serrata
Isonychia sp.
Baetis quebecensis
Baetis sp.
Pseudocloeon sp.
Stenonema vicarium
Stenonema sp.
Ephoron sp.

Odonata

Lanthus albistylus

Plecoptera

Acroneuria sp.

Hemiptera

Saldidae

Coleoptera

Stenelmis sp.
Helichus fastigiatus
Helichus limnophilus
Gyrinus sp.

Trichoptera

Cheumatopsyche spp.

Station II. Continued.

Diptera

Protoplasa fitchii
Hexatoma spp.
Guttipelopia sp.
Chironomidae (Pentaneurini)
Simulium species A (Johannsen)
Simulium spp.

Crustacea

Decapoda

Orconectes putnami

Mollusca

Gastropoda

Pleurocera sp. (shell only)

Nematoda

Station III

Arthropoda

Insecta

Ephemeroptera

Stenonema sp.

Odonata

Dromogomphus spinosus
Agrion maculata

Hemiptera

Hebrus sp.
Microvelia sp.
Rheumatobates sp.

Coleoptera

Dineutus discolor
Haliplus sp.
Elmidae

Trichoptera

Cheumatopsyche spp.
Hydroptilidae
Psychomyiidae

Megaloptera

Corydalus cornutus
Sialis sp.

Station III. Continued.

Diptera

Chaoborus spp.
Culicidae
Nilothawma sp.
Phaenopsectra sp.
Rheotanytarsus exiguus
Cricotopus sp.
Chironomidae
Simulium species A (Johannsen)
Simulium vittatum
Simulium spp.
Hemerodromia sp.
Dolichopodidae

Crustacea

Decapoda

Orconectes putnami
Orconectes sp.

Mollusca

Pelecypoda

Eulamellibranchia

Sphaerium sp.
Fusconaia flava
Villosa sp.
Actinonaias carinata
Lampsilis ovata
Lampsilis teres (shell only)
Leptodea fragilis
Ptychobranchus fasciolare
Obovaria subrotunda
Unidentified immatures

Gastropoda

Unidentified (shells missing)

Station III. Continued.

Annelida

    Clitellata

        Oligochaeta

            Lumbriculidae

Nematoda

Platyhelminthes

    Turbellaria

Station IV

Arthropoda

Insecta

Odonata

Boyeria vinosa

Coleoptera

Dineutus discolor

Trichoptera

Cheumatopsyche sp.

Diptera

Chaoborus sp.
Phaenopsectra sp.
Simulium spp.

Crustacea

Decapoda

Orconectes spinosus
Orconectes sp.

Mollusca

Pelecypoda

Eulamellibranchia

Sphaerium sp.
Amblema plicata
Elliptio dilatatus
Elliptio crassidens
Tritogonia verrucosa
Actinonaias carinata
Leptodea fragilis
Ptychobranchus fasciolare

Station IV. Continued.

Gastropoda

Pleurocera sp. (shell only)
Unidentified (shells missing)

Nematoda

Station V

Arthropoda

Insecta

Ephemeroptera

Stenonema vicarium
Stenonema tripunctatum
Stenonema sp.
Ephemerella attenuata

Odonata

Boyeria vinosa

Coleoptera

Stenelmis spp.
Ancyronyx variegata
Dineutus discolor
Galerucella sp.

Trichoptera

Cheumatopsyche sp.

Diptera

Psectrocladius
Phaenopsectra sp.
Stempellina
Rheotanytarsus exiguus
Chironomidae
Simulium vittatum
Simulium sp.
Hemerodromia sp.

Crustacea

Decapoda

Orconectes spinosus
Orconectes sp.

Station V. Continued.

Isopoda

Asellus sp.

Mollusca

Pelecypoda

Eulamellibranchia

Amblema plicata
Elliptio dilatatus
Actinonaias carinata
Proptera alata

Annelida

Clitellata

Oligochaeta

Lumbriculidae

Station VI

Arthropoda

Insecta

Ephemeroptera

Stenonema tripunctatum
Stenonema sp.

Plecoptera

Pteronarcys sp.

Coleoptera

Dineutus discolor

Diptera

Simulium species A (Johannsen)
Simulium spp.

Mollusca

Pelecypoda

Eulamellibranchia

Amblema plicata
Elliptio dilatatus
Fusconaia flava
Megalonaias gigantea
Pleurobema cordatum
Pleurobema sp.
Quadrula pustulosa
Actinonaias carinata
Lampsilis ovata
Proptera alata
Ptychobranchus fasciolare
Villosa sp.

APPENDIX B

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